COMMONWEALTH OF PENNSYLVANIA

DEPARTMENT OF INTERNAL AFFAIRS

GUIDE TO THE GEOLOGY OF CORNWALL, PENNSYLVANIA

by

Carlyle Gray
Davis M. Lapham

TOPOGRAPHIC AND GEOLOGIC SURVEY

BULLETIN G 35

1961

ADDITIONAL COPIES
OF THIS PUBLICATION MAY BE PURCHASED FROM
BUREAU OF PUBLICATIONS
DEPARTMENT OF PROPERTY AND SUPPLIES
HARRISBURG, PA.

Frontispiece

Magnetite ore which has replaced limestone above diabase in the open pit at Cornwall (Photo courtesy of Bethlehem Steel Corp.)


LIMESTONE
MAGNETITE
ORE
DIABASE

PENNSYLVANIA
GEOLOGICAL SURVEY
Fourth Series
BULLETIN G 35

GUIDE TO THE GEOLOGY OF CORNWALL, PENNSYLVANIA

by

Carlyle Gray
Davis M. Lapham

DEPARTMENT OF INTERNAL AFFAIRS
Genevieve Blatt, Secretary
TOPOGRAPHIC AND GEOLOGIC SURVEY
Carlyle Gray, State Geologist

1961

FOREWORD

This report is a description of the geology of the iron ore occurrence at Cornwall, Pennsylvania, for the use of geologists and mineral collectors visiting the area. The guide is an outgrowth of a larger study of the geology, mineralogy, and genesis of the Cornwall ore body which is still in progress.

The reader is reminded that permission must be obtained from the mine office to search for mineral specimens in and around the mines. An excellent, overall comprehension of the geology may be obtained by viewing the outcrops along the public roads.

Genevieve Blatt,
Secretary of Internal Affairs

CONTENTS

ILLUSTRATIONS

Frontispiece

Figures

ILLUSTRATIONS

Plates

GUIDE TO THE GEOLOGY OF CORNWALL, PENNSYLVANIA

by

Carlyle Gray and Davis M. Lapham
Pennsylvania Geological Survey

ABSTRACT

Cornwall, Pennsylvania, is a well-known mining locality which is of interest from historical, economic, and geologic viewpoints. The history of the magnetite mining operations from 1742 to 1960 is briefly reviewed. The ore is spatially and genetically associated with a Triassic diabase sheet which is intrusive into folded and faulted, lower Paleozoic limestones. Clastic Triassic sediments unconformably overlie the limestones. The ore replaces beds of the Buffalo Springs Formation, the oldest of five Cambrian units mapped in the area. The magnetite ore is associated with chalcopyrite, pyrite, earlier amphiboles and pyroxenes, and later silicates such as mica, chlorite, and zeolites. Both the structure and the mineralogy of the ore deposit indicate that it is genetically related to the diabase, although somewhat later in time than the crystallization of the diabase.

LOCATION

The Cornwall Iron Mines are located in Lebanon County, Pennsylvania, near Highway Route U. S. 322 about one-half mile south of the village of Cornwall in the southeast rectangle of the Lebanon 7½ minute quadrangle. Cornwall is six miles south of Lebanon and 30 miles east of Harrisburg. The topography is a rolling one with a relief of 500 feet.

Geologically, the deposits are located at the northern edge of the Triassic basin where Cambrian limestones are in contact with a diabase intrusive of Triassic age. There are three ore bodies being mined (Fig. 1). The western ore body has been worked from the surface and underground; the eastern is an entirely underground operation. The Elizabeth Mine is a small open pit operation between these two.

HISTORY

The iron ore mines at Cornwall are the oldest continuously operated mines in the Western Hemisphere. Iron ore is reported to have been discovered here by Peter Grubb in 1732. The magnetite ore cropped out on three hills: Big Hill, Middle Hill, and Grassy Hill.

In 1742, Peter Grubb built a furnace near the ore deposit, naming it the Cornwall furnace after the English mining county where his father was born. This furnace operated continuously for 141 years, utilizing the local iron ore and charcoal made nearby. It produced such products as cannon, shot, stoves, and other items for the Continental Congress during the American Revolution. The furnace still stands in its original condition about one-fourth mile north of the open pit and may be visited under the direction of a guide.

The area has been worked for ore continuously since 1742. Through the first century or more of operation, ownership was very diverse, but

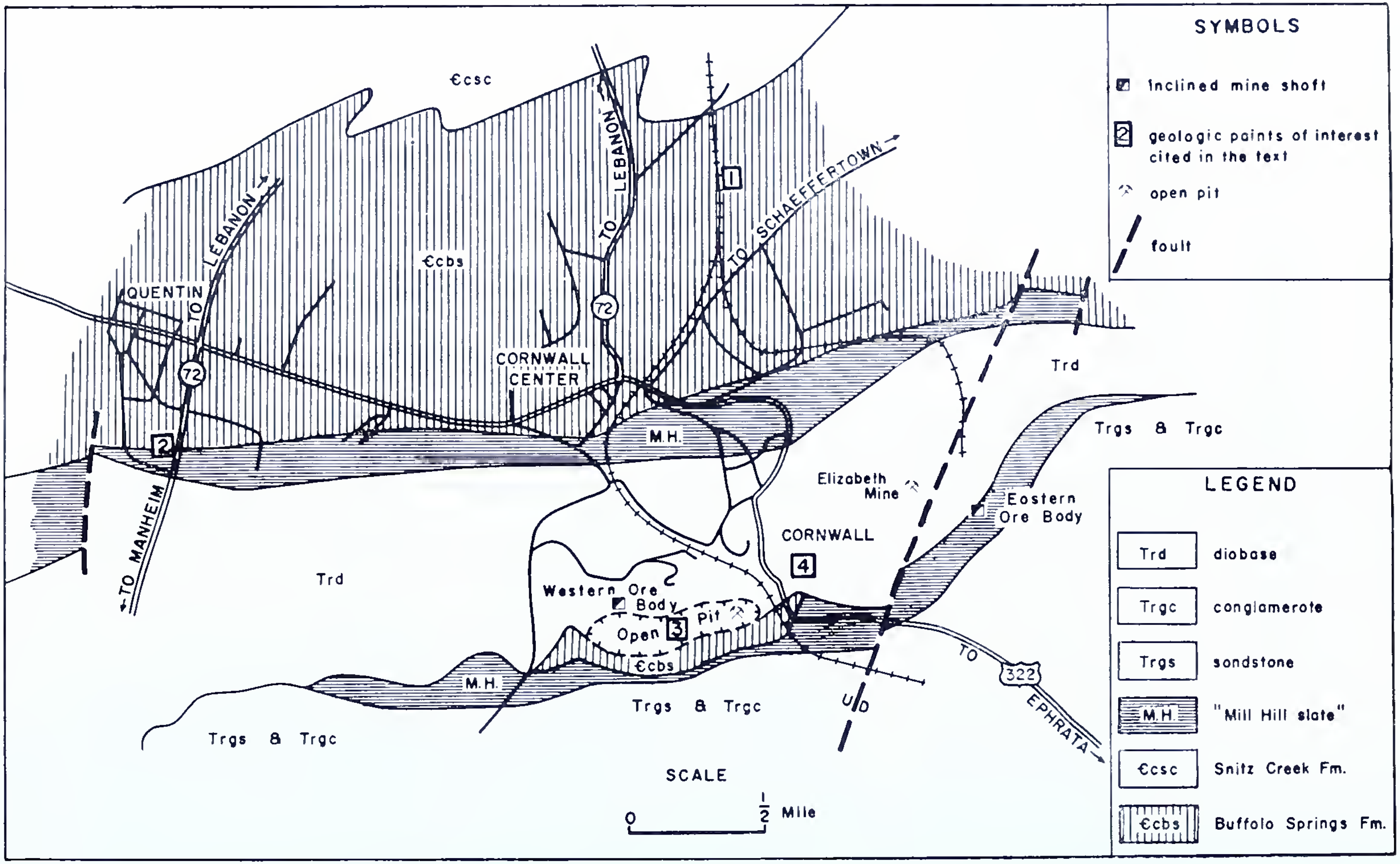


Figure 1. Location map, Cornwall and vicinity, Lebanon County.

in 1864 the Cornwall Ore Banks Company was formed, which consolidated 95 of the 96 holdings. From 1916 to 1921 Bethlehem Steel Corporation gradually acquired ownership of the Cornwall Ore Banks Company. In 1926 it purchased the Robesonia Iron Company and for the first time the ownership of the entire area was in the hands of a single corporation.

The eastern ore body was not discovered until 1919 when it was located by a dip needle survey. Its discovery, however, had been forecast by Spencer (1908, p. 23) who said, "All of this ground (from Miners Village) as far as the road leading from Rexmont to Overlook is regarded as likely to contain a continuation of the Cornwall ore bed".

The western ore body was worked entirely by open pit methods (Fig. 1) until 1921, when an inclined shaft was sunk near the western end of the open pit. Underground mining by sublevel stoping and shrinkage stoping was carried out in the deeper parts of the orebody until 1940. From 1940 to 1953, operation was by open pit only. In 1953 underground mining was resumed when all of the ore that could be mined by open pit methods had been removed.

Two inclined shafts were sunk in the footwall of the eastern ore body in 1927 and 1928. Development in this ore body was halted by the depression in 1931 before any significant quantities of ore had been produced. Mining was resumed in 1937. The ore is mined by panel caving, a modification of block caving.

The Elizabeth open pit was begun in 1960. The total tonnage of ore here is relatively small. A separate crusher has been set up to handle this operation.

With the exception of veins of supergene-enriched copper recovered from the oxidized zone by selective mining in the early days, iron was the only metal recovered until shortly after 1920. At this time a combination magnetic-separation and froth-flotation plant was built in Lebanon to remove the sulfides from the ore to reduce its sulfur content. In 1960 it was decided to move the separation plant from Lebanon to the mining area. Differential froth flotation makes it possible to separate the chalcopyrite from the pyrite so that copper is now an important by-product. The pyrite concentrates contain about one per cent of cobalt, and until recently Cornwall was the leading domestic producer of cobalt. Sulfur (sulfuric acid) is recovered in the roasting of the pyrite. Gold and silver in appreciable quantities (1700 oz. of Au in 1953) are derived from the refining of the copper. Thus, at present the mine is producing five metals and one non-metal. In addition, the limestone overburden removed from the pit is being crushed and sold for aggregate. The present production is around one million tons of ore per year. The grade of the ore averages 40-42% Fe. The magnetic concentrates contain about 62% Fe. Phosphorus and titanium are not present in any significant quantity.

STRUCTURE

Geologically, the deposit is a contact metasomatic deposit at the contact of a Triassic diabase sheet and Cambrian limestones. The intrusive in the vicinity of the ore is a dike 1000 to 1200 feet thick and dips 40-45°S. at the surface (Fig. 2). This dike is part of a basin-shaped sheet, in part cross-cutting, and in part concordant, which has an elliptical outcrop pattern three miles wide by six miles long. On its northern edge the sheet follows approximately the contact between the northerly dipping Triassic sediments and the southerly dipping, folded, Paleozoic sediments of the Great Valley. At Cornwall a wedge of the Paleozoic sediments lies above the sheet and this wedge contains the major ore bodies (Fig. 2 and Plate 2). The ore lies directly above the diabase and in general it conforms to the somewhat irregular topography of the top of the sheet (Fig. 3).

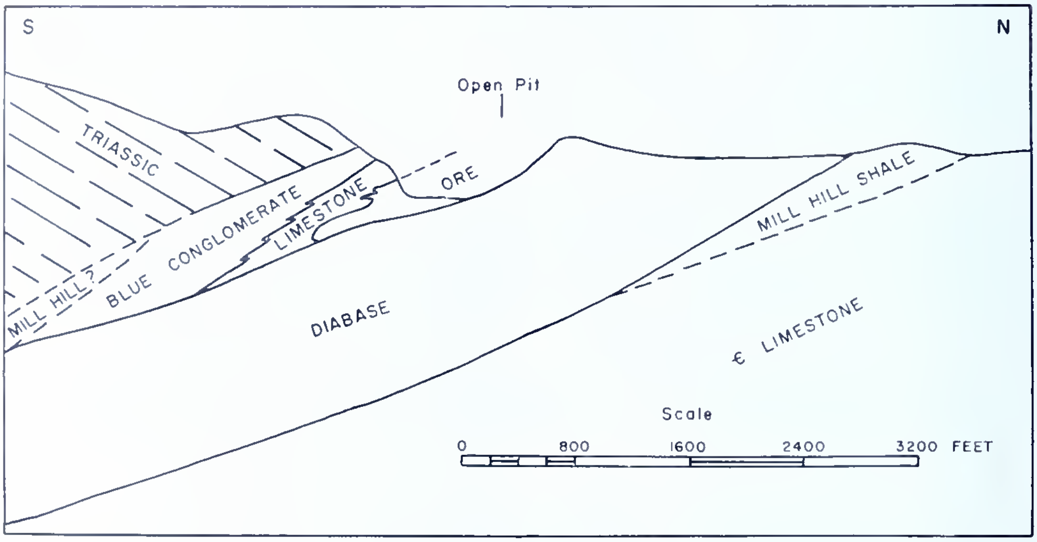


Figure 2. Generalized cross section of the Cornwall ore body as seen from the highway.

STRATIGRAPHY

Upper Cambrian: Conococheague Formation

As the result of detailed mapping and the combination of incomplete sections it has been possible to divide the Conococheague Formation into five members. These members are lithologic units and no key fossils have been found as yet. It is not certain that all the members belong within the Conococheague Formation as defined by Stose (1908). They are, however, clearly mappable units.

The *Buffalo Springs Member* is the oldest mappable unit in the Conococheague Formation. It consists of white to pinkish-gray crystalline limestone (usually with thin shaly laminae), alternating with buff-weathering,

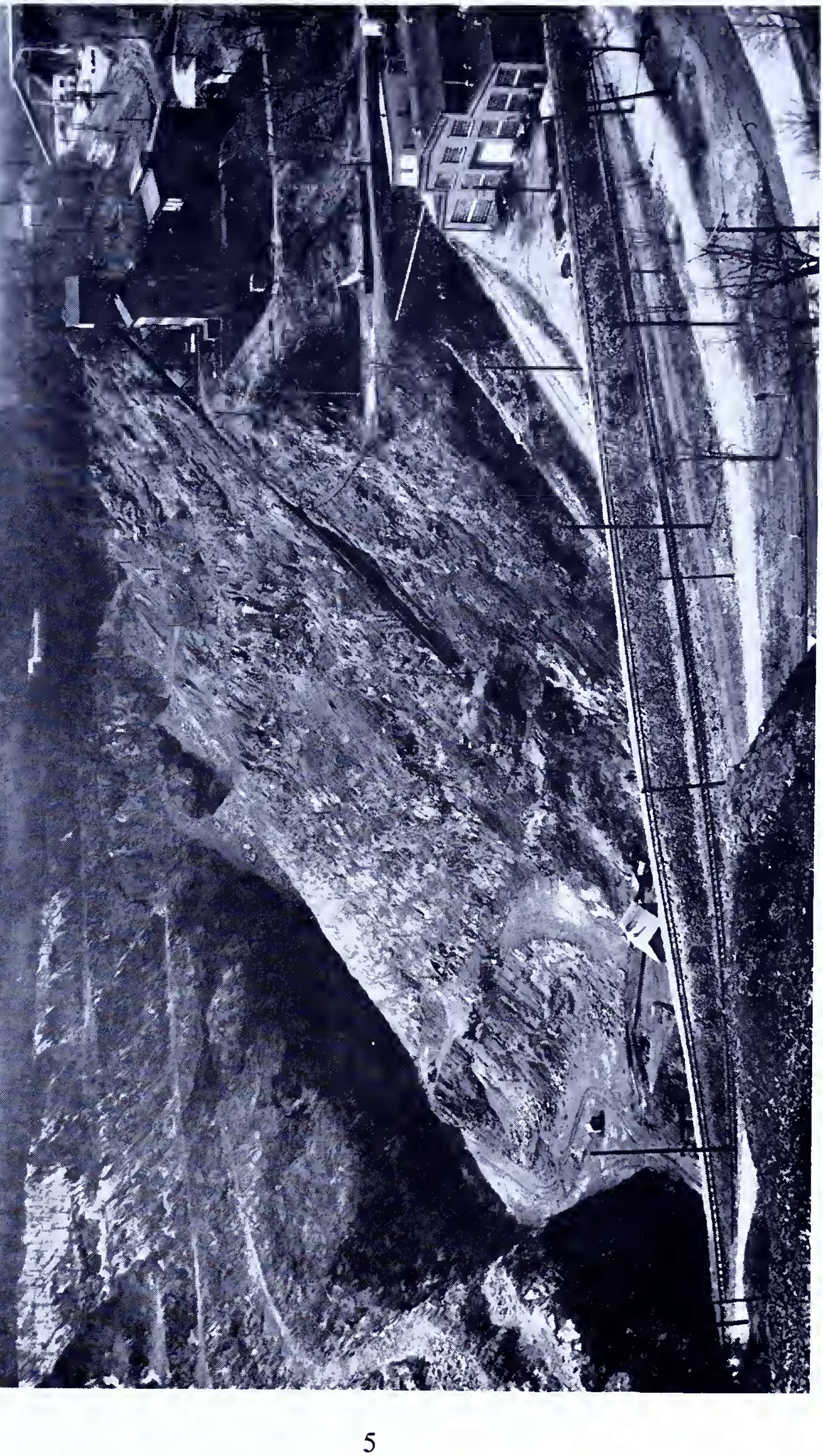


Figure 3. The top of the southerly dipping diabase sheet at the ore footwall looking west. (Photo courtesy Bethlehem Steel Corp.)

light-gray, dense dolomite and magnesian limestone. The white limestones often grade laterally into light-gray to bluish-gray, finely crystalline limestone; locally both types are oolitic. Light-gray limestone is most common near the top of the member. A type of algal structure generally called cryptozoon is the only fossil which has been found. They are also most common near the top of the member. Thin, sandy to silty limestone beds occur and can be traced for short distances. Buff-weathering, shaly limestone interbeds also are present in many outcrops. Cleavage is commonly well developed in the limestone and shaly limestone beds, often to the point of obliteration of the bedding. Extreme drag folding and flowage is common. Large pyrite crystals were found in the soil at one locality.

One of the best exposures of the Buffalo Springs Member is in a railroad cut one-fourth mile north of Cornwall Center (location 1, Figure 1). The beds exposed here are in a complex anticline with a double crest. The cross section (Plate 1) shows most of the larger structures as seen in the eastern side of the cut, although it is not the only possible interpretation. The beds exposed are typical of the Buffalo Springs Member. There is an abundance of pinkish-gray and bluish-gray crystalline limestones with buff-weathering dolomitic and shaly interbeds. Near the center of the cut a few sandy beds are exposed.

Boudinage structures and drag folding of the beds are well illustrated at the northern end of the cut. Here dolomite beds occur in tight, isoclinal folds of low amplitude. The limestone has acted in a completely plastic fashion and flowed from the cores of the folds around the more competent dolomite (Fig. 4).

The *Snitz Creek Member* consists of massive, gray, crystalline dolomite, commonly oolitic, with some bluish-gray limestone or dark-gray, shaly limestone interbeds. The dolomite varies from densely to coarsely crystalline. Where coarse grained, it is also vuggy. Shaly partings, commonly stylolitic, occur in the dolomite. A number of quartzose sandstone beds are present. The sandstone generally has a dolomitic cement; fresh rock is gray, but becomes brown and porous when weathered. Sand grains locally grade into silt. In some places the sandstone beds grade into dolomite with abundant floating quartz grains. Dark-gray to gray chert is locally abundant.

This member has a stratigraphic position and lithology similar to the Big Springs Station Member (Wilson, 1952) of the Conococheague Formation. It is estimated to be 250 to 300 feet thick.

The *Schaefferstown Member* consists of medium-gray limestone with distinct shaly bands. Fresh exposures appear thick-bedded, but when weathered the rock appears shaly. Patches and thin beds of dark-gray calcarenite are characteristic. Dolomitic beds are rare. Near the base, some pinkish-gray beds occur. The shaly bands and laminae are carbonaceous and make the member particularly susceptible to flowage. As a

Figure 4. Tight isoclinal folds in the Buffalo Springs Member in which limestone flowed around more competent dolomite cores.

consequence, well preserved cryptozoons are not common. The thickness is unknown for the same reason. It may be on the order of 200 to 500 feet.

The base of the Schaefferstown Member is placed at the top of the last massive dolomite bed of the Snitz Creek. The top of the Schaefferstown Member is drawn at the first appearance of the pinkish-gray or white crystalline limestone of the Millbach Member (Fig. 5).

Figure 5. A cryptozoon reef in the Millbach Member.

The *Millbach Member* is distinguished from the Schaefferstown Formation by the presence of pinkish-gray or white crystalline interbeds, and less distinct shaly partings and bands in the bluish-gray limestone beds. This formation is lithologically very similar to the Buffalo Springs Member and is distinguished principally by stratigraphic position, although apparently the Millbach Member has larger proportions of light-gray to bluish-gray limestone beds than the Buffalo Springs Member. A few, thin, quartzose and sandy limestones or dolomites are present. Cryptozoons

have rarely been found in this area, but in part this may be the result of rather poor exposures of the member. Immediately to the east of Cornwall, cryptozoon reefs are common.

The *Richland Member* at its base consists of massive, gray, cherty dolomites which frequently are oolitic. The oolites are large and are present both in the chert and the dolomite. In the eastern part of Lebanon County, this member is quite thick; it contains limestones in its middle section, and is dolomitic at top and bottom. The cherts may or may not be oolitic. They are usually gray to light gray in color, but some non-oolitic chert that is almost white occurs.

In the excellent exposure east of Richland, on the Reading Railroad, the upper part of the member appears to reflect cyclic sedimentation. Gray, siliceous dolomites are repeated at least twelve times. These beds are usually overlain by limy dolomite, magnesian limestone, or banded limestone and dolomite. The bands are often broken, forming a conglomerate. Above this are typically gray to light-gray dolomites with shaly partings or bands. The sequence then begins again with siliceous dolomite.

The limestone at the Cornwall ore body apparently belongs to the Buffalo Springs Member in the Conococheague Formation. Recrystallization and replacement have so altered the appearance of these beds that correlation based on lithology is difficult.

The limestone beds vary from massive to finely laminated or banded textures with shaly and silty bands. The texture varies from dense to coarsely crystalline. In chemical composition, the beds are divided almost evenly between impure limestones and impure magnesian limestones. Dolomites are rare, and even the magnesian limestones are nearer the composition of limestone than of dolomite when plotted on a triangular ($CaCO_3$-$MgCO_3$-insol) diagram. These figures are from 49 analyses of limestones in the hanging wall of the open pit ore body. In general, the laminated or shaly, banded beds are more magnesian. Analyses of three dolomite samples show that the silica content is very high (over 20% SiO_2). Many of the beds sampled can be traced visually into the ore and it is thought that the analyses are fairly typical of the replaced beds. Where the siliceous bands were present, a concentration of Fe-Mg silicates formed during metasomatism.

Ordovician (?)

"Mill Hill slate" and "blue conglomerate" are local names given to two units known only in the vicinity of Cornwall. They occur both above and below the diabase intrusive, but always within the contact metamorphic zone.

The "Mill Hill Slate" is recognized as such only where there has been considerable alteration by thermal metamorphism. It is a hard, dense,

light-brown to black, banded hornfels largely comprising quartz and sericitic muscovite. Locally it contains a small amount of calcium carbonate. Relict bedding is preserved by the color banding. The "Mill Hill slate" is believed to be an outlier of Martinsburg shale which has been altered by the diabase intrusive. The Martinsburg Formation normally lies on Middle Ordovician limestones, but apparently overlapped older rocks south of its main belt of outcrop.

A good exposure of the "Mill Hill slate" lying between the footwall of the diabase and the Buffalo Springs Member is located one-fourth mile south of Quentin on Pa. Route 74 (location 2, Figure 1). Typical "Mill Hill" hornfels is here interbedded with "blue conglomerate". Faulting is evident, and minor drag folds are visible. Pyritic zones are common and their alteration formed acid ground waters which have decomposed the rock. Petrographic thin sections show recrystallized calcite veins and calcite-tremolite-quartz veins in an iron-stained and iron-clouded matrix of fine-grained quartz and mica. Relict pebbles, broken and replaced, are present.

The "blue conglomerate" is also of problematical age and origin. Where least metamorphosed, it appears to consist of pebbles, cobbles, and boulders of quartz in a carbonaceous shale matrix; the pebbles are mostly subangular. Andradite garnet, chlorite, and hematite are locally abundant. In thin section the quartz 'pebbles' are revealed to be composed of interlocking and fused quartz grains which are often partially replaced by mica. These quartz aggregates are scattered throughout a matrix of directionally oriented mica with minor carbonate and chlorite. Both the petrographic and field evidence suggest that the present distribution and texture of the "blue conglomerate" is in part of tectonic origin.

In some places the "blue conglomerate" definitely overlies the "Mill Hill slate." Elsewhere the "Mill Hill slate" grades laterally into "blue conglomerate" such that the "blue conglomerate" directly overlies the limestone. In many drill holes and a few outcrops, the "blue conglomerate" appears to be interbedded with both "Mill Hill slate" and the limestone. In some areas of closely spaced drilling, cores containing alternating "blue conglomerate" and limestone cannot be correlated. This could be interpreted to mean that the conglomerate actually contains large blocks of limestone. In a wall of the open pit, however, a tongue of "blue conglomerate" is clearly interbedded with limestone. To add to the complexity, this tongue grades laterally into "Mill Hill" lithology.

These features, combined with the fact that no similar conglomerate has been observed associated with other outliers of the Martinsburg Formation, suggest that the "blue conglomerate" is a phase of the "Mill Hill slate" and may be in part, at least, a tectonic breccia related in some way to peculiar structural features that controlled the deposition of ore at Cornwall.

Triassic: Newark Group

The New Oxford Formation makes up the lower part of the Newark Group, but does not occur in the vicinity of Cornwall.

The upper part of the Newark Group is the Gettysburg Formation, consisting of red shales, quartzose red sandstones, and quartz conglomerates, which has overlapped the New Oxford Formation and unconformably overlies the Paleozoic limestones at the Cornwall mine (Geyer and others, 1958).

The three rock types of the Gettysburg Formation are generally interbedded. The shales contain ripple marks and mud cracks, and are relatively non-micaceous. The sandstones contain rounded to subrounded quartz grains and hematite (which accounts for the red color); cross bedding, stream channels, and occasional ripple marks are present. The quartz conglomerate, a ridge-former in this area, is very thick bedded and contains thin sandstone interbeds. The conglomerate contains quartz particles ranging up to cobble size; the groundmass contains detrital quartz grains, hematite, and clay minerals cemented either by carbonate or silica.

Close to the intrusive and the ore deposits, the Triassic rocks have been bleached from their normally red color. Scattered grains of garnet (andradite) and specular hematite are frequently present.

IGNEOUS PETROGRAPHY

The intrusive pluton underlying the ore bodies at Cornwall is diabase, quite similar to the intrusives found elsewhere in the Triassic basin. It is composed essentially of plagioclase and pyroxene showing typical ophitic to sub-ophitic texture, with accessory ilmenite, magnetite, and biotite. Quartz and orthoclase are present in interstitial micropegmatite near the top of the diabase. The plagioclase is mostly andesine to labradorite occurring in well formed laths. The feldspar phenocrysts in the chilled zone are more calcic. Some zoned crystals have been observed. Exsolution microperthites are also present. Orthoclase and microcline are present as a few separate crystals and as oriented, exsolved intergrowths in the diabase and in the micropegmatite. In the upper part of the dike, pyroxenes are about evenly divided between pigeonite and hypersthene, with augite also present (Gray, 1956). Lower in the dike, the ortho-pyroxene becomes dominant. Altered and inverted orthopyroxene phenocrysts are also present in the chilled zone. The large grains of hypersthene show "exsolution" type textures representing a mixture of ortho-and clino-pyroxenes.

Hickok (1933, p. 200) divides the normal diabase into four facies: "glassy contact facies, crystalline contact facies, intermediate facies, and coarse facies". These are based on grain-size variations and all show similar composition. In addition, he describes the following abnormal facies that show considerable differences in mineralogy: diabase pegmatite, aplite, and altered diabase.

The diabase pegmatite is most common in the upper third and lower third of the dike. It consists of long crystals of pyroxene, mostly augite, in a ground mass of coarse-grained feldspar and micropegmatite. Titaniferous magnetite is abundant. The pegmatite occurs both as dikes with definite boundaries and irregular schlieren, both within the confines of the diabase. This is also true of the fine-grained pink aplite. The aplite consists of pink feldspar, probably orthoclase, dusted with hematite, quartz, pyroxene, and mica, with locally abundant ilmenite.

ORE DEPOSITS

Ore Structure and Texture

The more westerly of the two major ore bodies at Cornwall was exposed at the surface and has been worked both from the open pit and underground. The ore body had an outcrop length of 4400 feet and a dip length of about 1000 feet. The plunge is to the west so that the deepest part is near the western end where the #3 shaft is located. The open pit was worked to the maximum economic depth, about 500 feet below the surface. The ore has a thickness here of about 150 feet.

The hanging wall of this western ore body is entirely limestone. The limestone is well exposed in the southern face of the open pit (location 3, Figure 1). The limestone is considerably contorted and is apparently isoclinally folded. The beds in general dip north and northwest. The contact between the ore and limestone is quite sharp, but irregular. A detailed map and cross sections relating local structures to areas of magnetite concentration are shown in Plate 2. This can best be seen from Big Hill (location 4, Figure 1). Some of the beds were apparently more favorable to replacement, and tongues of ore can be seen penetrating the limestone. The ore consists principally of magnetite and Fe-rich amphibole. Chalcopyrite, pyrite, diopside, phlogopite, calcite, chlorite, and serpentine are also present in varying amounts. A great many other minerals have been found here, most of which are listed by Lapham and Geyer (1959, p. 47). The waste pile on Big Hill (location 4, Figure 1), is the best area for collecting these minerals; permission to enter this area must be obtained from the Cornwall office of Bethlehem Steel Corporation.

The eastern underground ore body has roughly the shape of a lima bean. The upper end is about 150 feet below the surface, while the lowest part is about 1200 feet below the surface. It is about 2500 feet wide at its widest part and reaches a maximum thickness of over 200 feet. The average thickness is probably less than 100 feet. It differs from the western ore body in that the hanging wall is formed by the "Mill Hill slate" and the "blue conglomerate". The upper contact is therefore sharper than that seen in the open pit since these units were impervious to ore replacement. The western end of this underground ore body does tongue into limestone, however.

The ore shows a variety of textures, most of which are inherited from the limestones. Most commonly it is banded with alternating black

magnetite-rich bands and green amphibole-rich bands. In some places the banding is broken up, giving the ore a brecciated texture. Elsewhere the ore is massive, with magnetite crystals scattered more or less uniformly through the silicate gangue. The pyrite and chalcopyrite are scattered irregularly through the ore as disseminations, as bands paralleling the magnetite bands, and as cross-cutting veinlets.

Locally, deposition of the ore was controlled by pre-existing rock structures, by composition of the host, and by host rock textures. Nearly east-west fractures, approximately parallel to the strike of the diabase, are the most consistently mineralized, containing magnetite, amphibole, and chlorite. Replacement banding is taken as evidence for preferential replacement parallel to bedding, and the crenulations or drag folds, which the ore followed, are probably not post-ore features, but represent a compositional control instead. Magnetite preferentially replaced "pure" limestone rather than shaly limestone, the latter having a higher concentration of silicate minerals. In order of decreasing susceptibility, magnetite preferentially replaced calcite, hematite, pyrite, mica, amphibole, pyroxene, and quartz. Thus, the kind and extent of pre-ore metasomatic silication also controlled magnetite deposition. Magnetite replaced moderately fine-grained minerals in preference to large porphyroblasts, the latter often acting only as a nucleation center for magnetite crystal growth.

Paragenesis and Mineralogy

Hickok (1933, p. 226) states that diopside attained a maximum concentration along the footwall of the western ore body, gradually decreasing toward the hanging wall, with a concomitant increase in amphibole concentration. A similar zonal arrangement was discussed by Callahan and Newhouse (1929). Recent evidence from the eastern ore body does not support a strictly inverse diopside-amphibole relationship. There is generally a second diopside maximum well above the footwall. Amphibole may also concentrate at the footwall. Although the details have not yet been thoroughly studied, it seems probable that a significant lateral variation in these silicates exists, in addition to variations between the footwall and the hanging wall. Plots of chemical analyses for Fe, Cu, and S for the eastern ore body also exhibit lateral and vertical variation. Maximum concentrations of Fe and S occur primarily at the footwall on the southwest of this ore body, and secondarily nearer the hanging wall to the north. Copper maxima show the reverse directional variation. Other field and petrographic data indicate that copper mineralization may have occurred separately in time from the magnetite-pyrite.

The following generalized paragenetic sequence for the eastern ore body differs only slightly from that given by Hickok (1933, p. 232) for the western ore body:

← OLDER YOUNGER →	STAGE
Quartz Calcite Feldspar	PRE-DIABASE
Mica Pyroxene (2 stages) Calcite Amphibole (coarse) Pyrite Amphibole (fine)	METASOMATIC SILICATE
Magnetite Chlorite Pyrite Chalcopyrite	ORE
Mica Quartz Calcite Chlorite Serpentine Zeolites	LATE HYDROTHERMAL

The major differences between this and Hickok's sequence are:

1) Some mica is pre-pyroxene and pre-amphibole;
2) Two periods of pyroxene and amphibole crystallization occurred;
3) Some pyrite crystallized prior to magnetite;
4) The alteration of mica to chlorite occurred during the introduction of magnetite; and
5) Hydrothermal, iron-rich mica is present.

It should also be noted that the amphibole extends over a continuous range from tremolite through actinolite to hornblende, much of it possessing the optical properties of hornblende. Optically speaking, there is very little true actinolite present, although positive identification must be withheld until chemical analyses are available.

Genesis of the Ore

The Cornwall magnetite ores have been considered to be a typical pyrometasomatic deposit ever since the reports by Spencer (1908), Callahan and Newhouse (1929), and Hickok (1933) on the western ore body. More recently the Pennsylvania Geological Survey has been engaged in a genetic study (Gray, 1956; Gray and Lapham, 1959) with emphasis on the more recently developed eastern underground ore body. The reference

of this deposit to the pyrometasomatic classification given by Lindgren (1933, p. 696) is based on the hypothesis that the ore is "derived from the solidifying diabase Magma" (Lindgren, 1933, p. 716) and by Hickok (1933, p. 253) who states that the ore solutions emanated from the adjacent diabase "where the slowly cooling interior of the intrusion formed a rest-magma . . . ". The major geologic evidence cited is the spatial ore-diabase association and a crude zonal mineral arrangement.

Some of the more important points bearing upon origin are as follows:

1. The Triassic diabase intrusives do not generally have extensive contact metasomatic aureoles, even where they intrude limestones. Locally, as at Cornwall, there is extensive metasomatic replacement of limestone, with formation of magnetite ore bodies. Thus, the development of magnetite is associated with contact metasomatism rather than just diabase intrusion.

2. The upper chilled zone of the diabase is locally replaced by magnetite, the amount of replacement decreasing downward into the diabase. Similarly the distribution of metasomatic silicates indicates a decreasing intensity of alteration away from the diabase-limestone contact upward toward the ore hanging wall. These data suggest that mineralization spread out from the intrusive contact.

3. The ore stage is paragenetically later than the metasomatic silicates, which are in turn later than the crystallization of at least the early stages of the diabase. Minerals from both the silicate and ore stages fill contraction cracks and joints in the upper diabase chilled zone.

4. Lateral variation plots of Fe, Cu, and total S exhibit a concentration at the southwestern corner of the eastern ore body, indicating that this may have been a source of directional flow for mineralizing solutions. This corresponds to the position of a major fault which transects the diabase and which is mineralized. Unit cell dimensions of magnetite decrease away from the southwest and may also be indicative of a source direction.

Although more work is in progress, it seems probable that the magnetite ores of Cornwall did not emanate directly from the cooling diabase sheet beneath the intruded limestones. More probably, the ore and preceding silicate metasomatism are related to the diabase through a common magmatic source. Following the diabase intrusion, mineralizing solutions migrated along the diabase-country rock contacts. With these modifications, then, Cornwall may be considered to be a pyrometasomatic deposit.

ACKNOWLEDGMENTS

Permission to release the mining and geological data on the Cornwall mine was granted by the Bethlehem Steel Corporation. Mr. Alan Geyer assisted in much of the field work and made contributions to the writing of this report.

REFERENCES

Callahan, W. H. and Newhouse, W. H. (1929), *The ore deposit at Cornwall, Pennsylvania,* Econ. Geology, v. 24, p. 403-411.

Geyer, A. R., Gray, Carlyle, McLaughlin, D. B., and Moseley, J. R. (1958), *Geology of the Lebanon quadrangle,* Pa. Geol. Survey, 4th ser., Bull. A 167c.

Gray, Carlyle (1956), *Diabase at Cornwall, Pennsylvania,* Pa. Acad. Sci. Proc., v. 30, p. 182-185.

―――――― and Lapham, D. M. (1959), *Cornwall iron mines,* Geol. Soc. America Guidebook, Pittsburgh, 1959, p. 147-152.

Hickok, William O. (1933), *The iron ore deposits at Cornwall, Pennsylvania,* Econ. Geology, v. 28, no. 3, p. 193-255.

Lapham, D. M. and Geyer, A. R. (1959), *Mineral collecting in Pennsylvania,* Pa. Geol. Survey Bulletin G 33, 74p.

Lindgren, Waldemar (1933), *Mineral deposits,* 4th edit., McGraw-Hill, N.Y., p. 696-716.

Spencer, Arthur C. (1908), *Magnetite deposits of the Cornwall type,* U. S. Geol. Survey Bull. 359, p. 1-102.

Stose, G. W. (1908), *The Cambro-Ordovician limestones of the Appalachian Valley in southern Pennsylvania,* Jour. Geology, v. 16, p. 698-714.

Wilson, James L. (1952), *Upper Cambrian stratigraphy in the central Appalachians,* Geol. Soc. America Bull., v. 63, no. 3, p. 275-322.

GLOSSARY

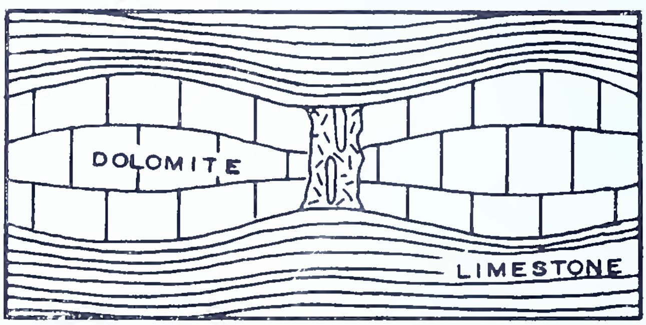
anticline An upfold or arch in the rocks, particularly in layered rocks.

aplite An igneous dike rock of fine-grained, granitic texture, usually light colored, and containing both quartz and orthoclase.

aureole A zone surrounding an igneous intrusive in which contact metamorphic or contact metasomatic effects have taken place.

bleaching The process of changing a colored rock, such as a red sandstone, to shades of gray or white.

boudinage A structure in which beds set in a yielding matrix, for example dolomite interbeds in limestone, are divided by cross fractures into pillow-like lenses as the result of intense deformation.



boudinage

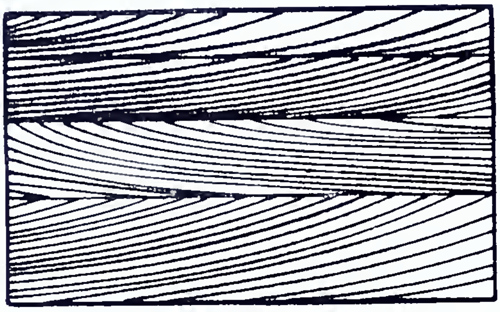
calcarenite A limestone or dolomite composed of calcite (or dolomite) sand, usually derived from corals and shells.

chilled zone That part of an igneous rock which is finer grained nearer the contact than is the rest of the igneous rock. The finer texture is the result of more rapid cooling.

competency The degree to which a rock resists deformation.

contact metamorphism Alteration which takes place at an igneous rock contact, usually restricted to changes occurring as a result of the heat given off by the cooling igneous body.

contact metasomatism An overall change in the composition of the rock near an igneous contact, other than the elimination of gases involved in simple metamorphism. See—metasomatism.



crossbedding

crossbedding Laminations of strata which formed from wind or current action during the accumulation of sediments. They are oblique to bedding planes and are often curved asymmetrically.

diabase An intrusive rock consisting essentially of calcic plagioclase and pyroxene, and characterized by a texture in which the grains of these minerals are intergrown.

dike A tabular body of igneous rock which cuts across the structures of the surrounding rock, or cuts through massive rock.

drag folds Folds produced in a rock by the relative movement of two enclosing, more competent rock units. The folds are generally small and are structurally related to the major folds in the region.

exsolution Means "unmixing" and is usually applied to the separation of two or more minerals from one previously existing mineral. It occurs during the cooling process of mineral crystallization.

floating grains Scattered grains of one mineral in a matrix of other material. The grains do not touch each other, hence the term "floating".

footwall The mass of rock below an ore bed, vein or fault, etc.

froth flotation A method of ore concentration in which minerals are separated by inducing differential adherence to the bubbles in a frothy, oil-water mixture. The desired minerals rise with the bubbles and are skimmed off the surface.

hanging wall The mass of rock above a bed of ore, vein, or fault, etc.

hornfels A fine-grained rock resulting from the baking of shaly rocks during contact metamorphism.

hydrothermal A term applied to heated emanations rich in water and other volatiles and to the minerals or rocks formed by deposition of elements carried in solution by these emanations.

inversion A change in crystal symmetry without significant changes in chemical composition resulting from a temperature change.

magma Molten rock below the Earth's surface.

magmatic A term applied to igneous rocks derived from a magma.

metasomatism The processes by which one mineral is replaced by another of different chemical composition owing to reactions set up by the introduction of material in solutions from external sources.

oolites A spherical to ellipsoidal particle, 0.25 to 2.00 mm. in diameter, which has a concentric or radial internal structure.

ophitic An interlocking or interpenetrating texture between grains.

outlier A portion of a rock unit which is separated from the main body of the rock unit. The separation is the result of the erosion of the intervening rock.

paragenesis A term relating to the sequence in which minerals have formed.

panel caving A method of ore removal in which strips of a tabular ore body are successively undercut and caused to cave into enlarged raises (bells), from which it is loaded into cars.

perthite An intergrowth of orthoclase or microcline with albite.

petrographic thin sections Rock slices usually ground to .03 mm. thickness and mounted on a glass slide which are used in studying mineral relationships with a petrographic microscope.

petrography That branch of science which deals with the systematic description and classification of rocks.

pluton A general term used to describe any body of igneous rock formed beneath the surface of the earth.

porphyroblasts Large mineral grains, crystals, or aggregates resulting from growth during deformation or metamorphism.

pyrometasomatism High temperature and high pressure metasomatism (see metasomatism).

sheet A tabular, intrusive, igneous rock in which thickness is small with respect to its other dimensions.

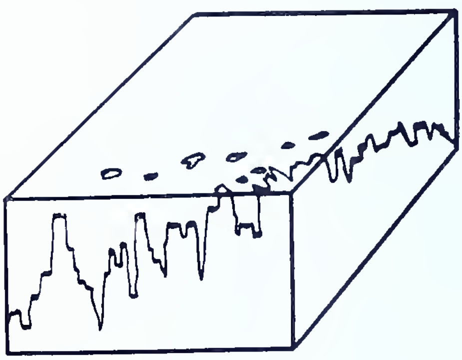
schlieren Tabular bodies from a few inches to a few feet in size occurring within an igneous rock.

supergene enrichment Minerals or ores formed from descending solutions.

stope An underground excavation for removal of ore, formed by mining the ore from a block of ground.

stylolite An irregular seam in a limestone in which the two sides interlock or interpenetrate. In cross section the stylolitic surface resembles the tracing of a stylus. The seam contains insoluble constituent minerals.

tectonic Of, pertaining to, or designating the rock structure and external forms resulting from the deformation of the rock.



a stylolite

tongue (of rock) A wedge-shaped body of rock which is an extension of the main rock unit.

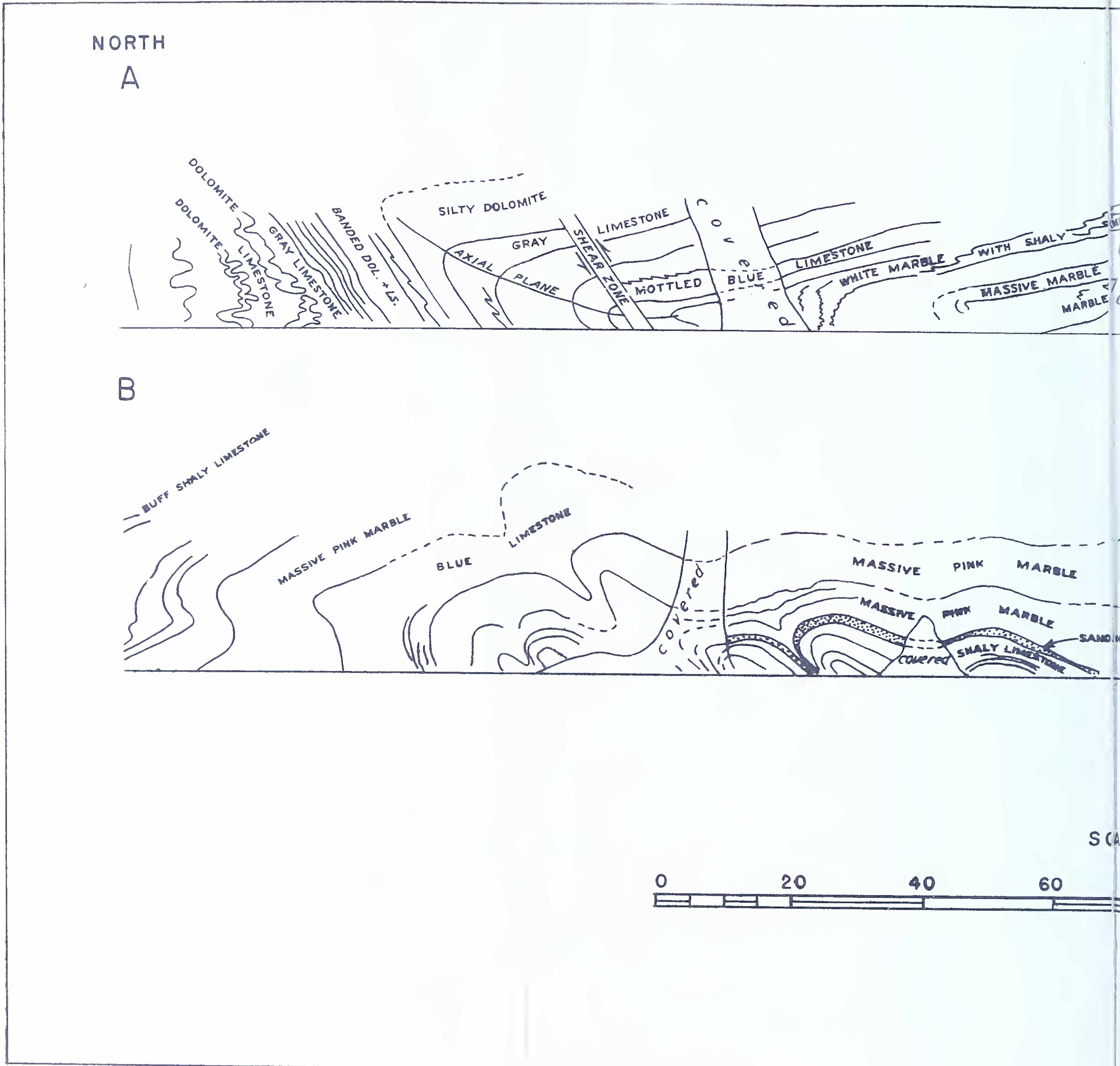
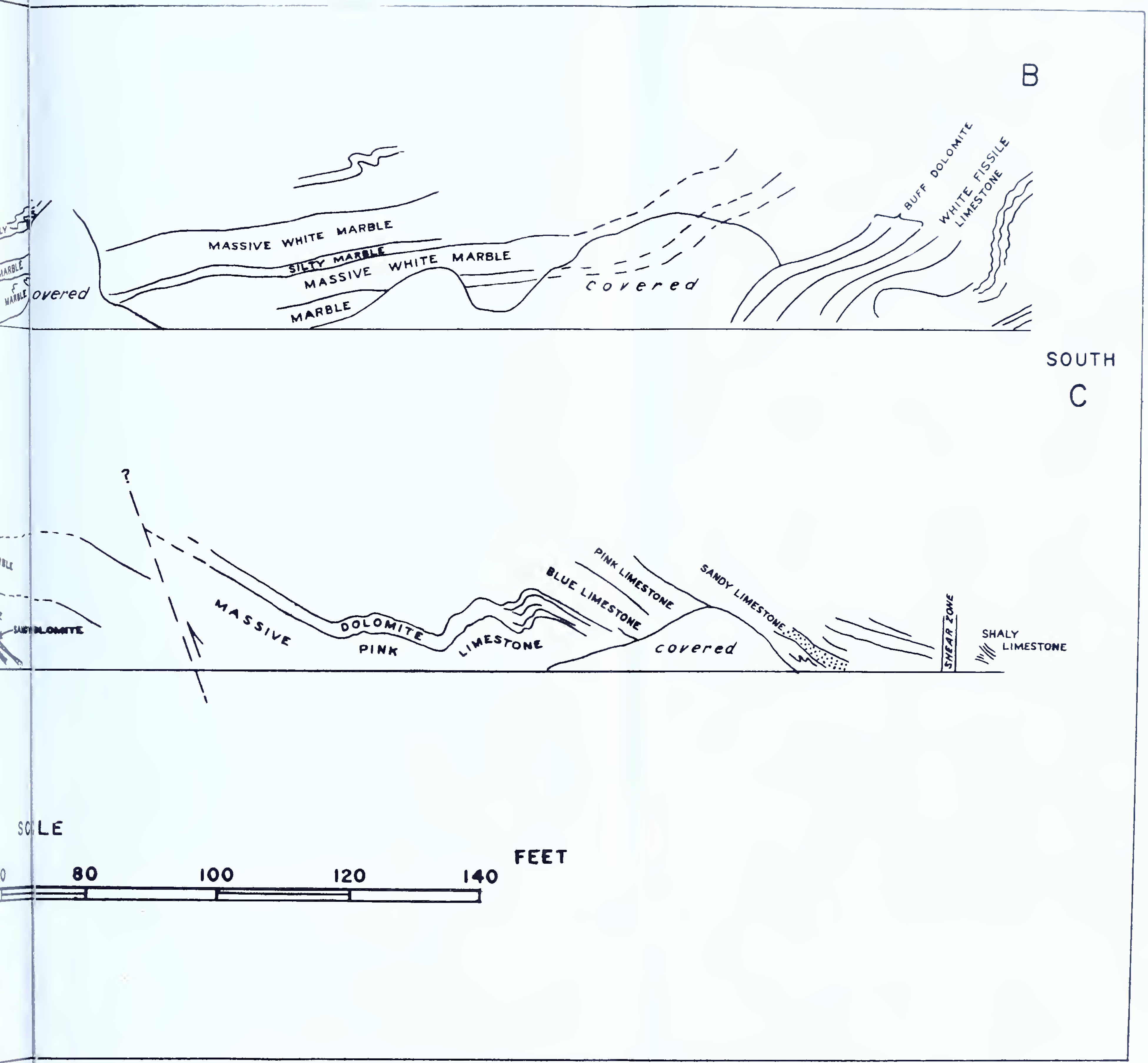
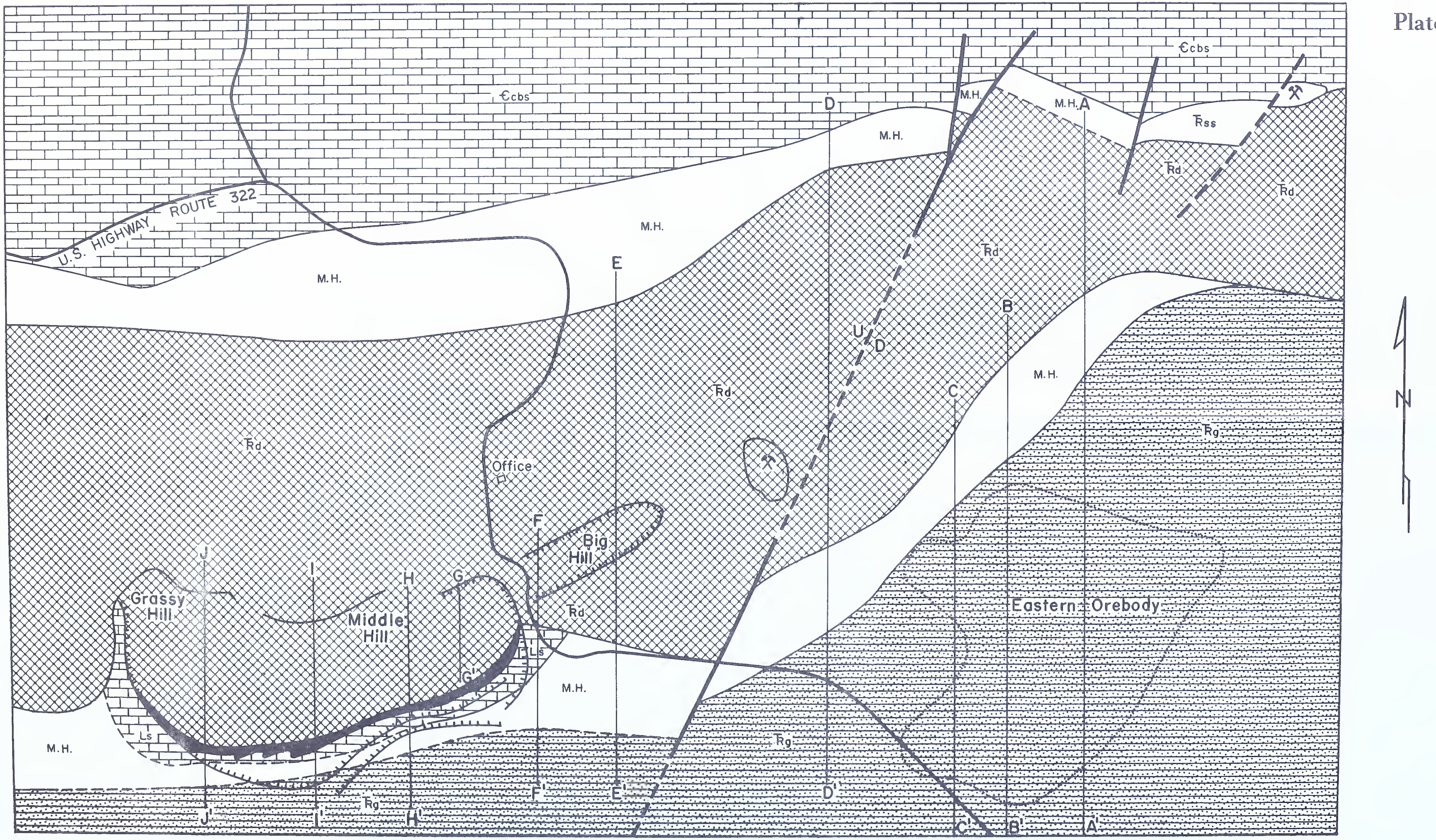


Plate 1. Cross section of the Buf

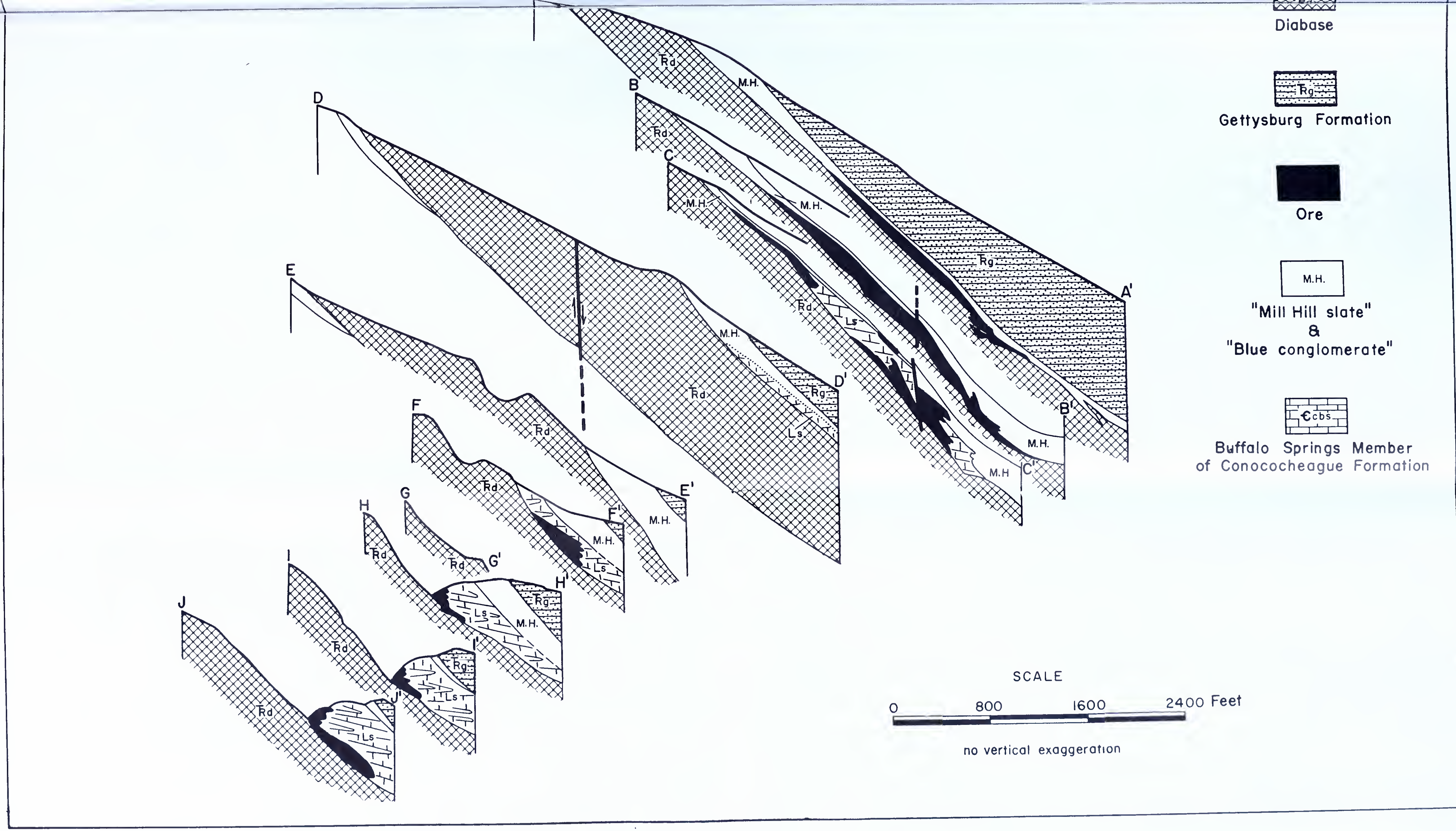


e Buff lo Springs Member at location 1, figure 1.

Plate 2.



LEGEND



Geologic map and cross sections at Cornwall, Pa.